Long-Term Human-Robot Teaming for Robot Assisted Disaster Response

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Mission

TRADR (Long-Term Human-Robot Teaming for Robot Assisted Disaster Response) *develops the science and technology to make the experience of a human-robot disaster response team persistent over multiple sorties during a prolonged mission.*

A real disaster response takes time. Whether to acquire situation awareness or to mitigate the disaster, disaster response teams perform multiple sorties into the area, spread over a span of days, months or even years, as witnessed for example in Italy (Emilia Romagna, 2012) or Japan (Fukushima, 2011).

Experience with robot deployment in such disaster response shows that multiple robots need to be sent into the area, together (synchronous operation) or one after another (asynchronous operation). Different kinds of robots play complementary roles in this process.

TRADR addresses the ensuing challenge of building integrated persistent situation awareness in unstructured dynamic environments gradually over multiple sorties, to allow a human-robot team to coordinate its efforts and learn over time to best execute its tasks.

The use cases addressed in TRADR focus on the response to a medium to large-scale industrial accident by teams consisting of human rescuers and several ground and airborne robots, who collaborate to explore the environment and gather measurements and physical samples. Changing teams take turns during a continuing mission extending over several days.

Collapsed buildings after a chemical plant accident, Moerdijk June 2011. Structural instability, danger of further explosions, water and air contamination.

Tank explosion, The Netherlads. Heat radiation, gas release, water and air contamination.

Objective 1: Persistent Environment Model

Construct models of dynamic environments, fusing multi-modal observations from different robots operating across multiple sorties. The result is a single world-centric model. It is persistent across the sorties, and its contents may change to reflect new observations. A robot can use this model to determine and localize activities, and register its own observations.

Objective 2: Persistent Multi-Robot Acting

Enable gradual adaptation and grounding of individual- and multi- robot task-level planning and execution within and across sorties, to reflect experience with operating in the disaster area. The result is the capability for multiple robots to learn how to better achieve exploration- or manipulation goals in a previously unknown, harsh environment. This is persistent: Robots learn within and across sorties during a mission. This self-development is based on the experience from interdependently acting and interacting with other robots, and with human team members (through shared control, human-in-the-loop).

Objective 3: Persistent human-robot teaming

Develop methods for the gradual adaptation of a robot's social skills to reflect experience from collaborating within a human-robot team, to improve trust and mutual understanding. The robot is explicitly aware of its own role within the team, and can reason how its own behavior can influence the dynamic interdependencies within the team. The result is the capability for a robot to become a better team player over time.

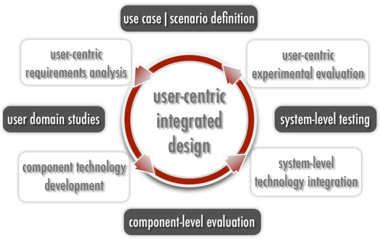
Partners

German Research Center for Artificial Intelligence, Germany | Delft University of Technology, Netherlands | Fraunhofer- Institute IAIS, Germany | Ascending Technologies GmbH, Germany | Swiss Federal Institute of Technology in Zurich, Switzerland | Royal Institute of Technology, Sweden | Czech Technical University in Praque, Czech Republic | Sapienza University of Rome, Italy | National fire Corps, Italy | Dutch Organisation for Applied Scientific Research TNO, Netherlands | United port and industrial Fire Department, Netherlands | Dortmund, Fire department, Institute of Fire Service and Rescue Technology, Germany

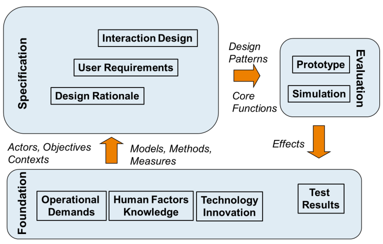
Approach

The TRADR project uses proven-in-practice user-centric design methodology, involving tight cooperation with end users and tight integration of technology.

In yearly cycles the project defines use cases in the industrial accident scenario, determines the user requirements, develops the corresponding system components, tests and integrates them and performs system-level evaluation in realistic conditions at end-user training sites in Italy, Germany and the Netherlands (top left-to-right).



To this end, TRADR advances the user-centric situated cognitive engineering design paradigm depicted in the scheme below. It places high priority on close collaboration with end users. The research questions of TRADR are motivated by real user needs, TRADR actively elicits user input in the design phases and verifies the technology by carrying out joint exercises and evaluation experiments, to test whether it meets user expectations. In this way TRADR also enables the users to actively experience this technology and to become aware of its potential and current limitations, to in the end facilitate its uptake.



Year 1 Exercise

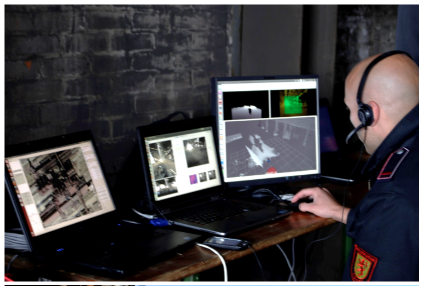
The first joint TRADR exercise took place in September 2014 at the ruins of an ex-military hospital in Calambrone, Italy (top left picture).

One team leader and two robot operators at a remote command post, a ground rover (UGV) and a quadcopter/microcopter with a pilot (UAV) performed assessment of a collapsed building. A tactical display facilitated shared situation awareness. The UAV was used for initial overview, the UGV explored inside the building. Team leader shift change occurred during the operation.

Year 2 Exercise and Evaluation

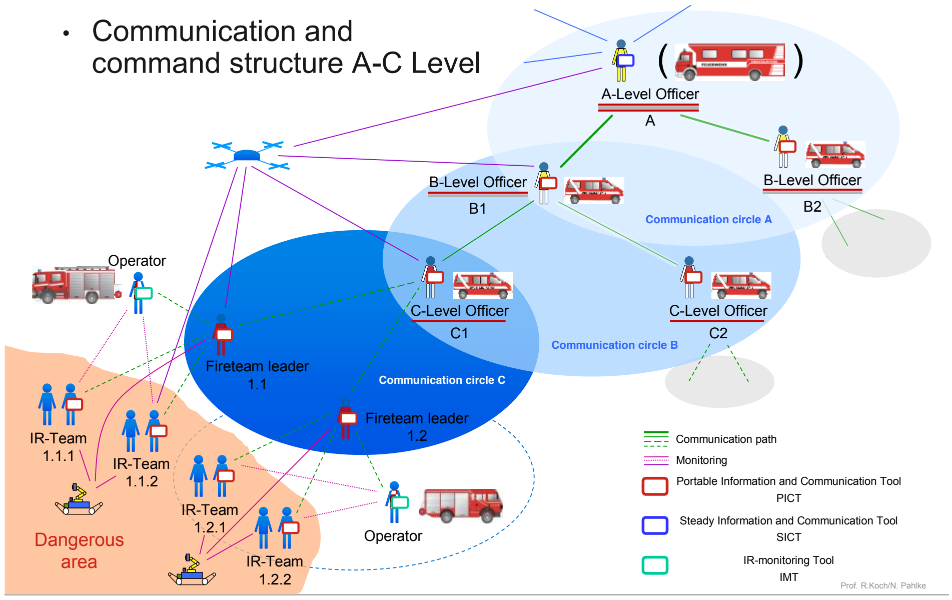
The second joint TRADR exercise and the year 2 evaluation took place in May and September 2015, respectively, at Phönix West, an abandoned furnace in Dortmund, Germany (top middle picture).

The team has been extended to include a mission commander, a team leader, two UGVs each with an operator, one UAV with an operator and a pilot. One of the UGVs had a camera-equipped arm.



The task was to assess a part of the building and search for victims and dangerous substances. The UAV was used for initial overview and search, the UGVs explored inside. Team leader shift change occurred during the operation. The mission continued over two days with different human teams. The second day team had access to the information and environment models gathered on the first day.

Partial autonomy features of the UGVs included adaptive traversability (the ability to adjust the flippers to the terrain) and driving autonomously to previously visited locations.



Year 1 Results

In Year 1 TRADR focused on multiple asynchronous sorties to assess a static disaster area. The goal was to enable a fixed human-robot team to gradually build up situation awareness multiple, asynchronous sorties. An integrated system was created and tested by the end-users during the first joint TRADR exercise. The system functionality encompassed some existing functionality from the NIFTi project (www.nifti.eu), migrated to an upgraged technical system framework, as well as significantly improved and newly developed TRADR functionality.

The TRADR human-robot team is embedded within a fire brigade command structure modeled on the disaster response command structures of the end-user organizations involved in TRADR. We focus on the command levels that are mostly involved in situation assessment and information exchange (picture above).

Based on an analysis of the team organizational structure reflecting the end-users' practices in disaster response missions we developed an initial ontology to represent team structure, roles, capabilities and organization. This facilitates reasoning with role-based social behavior at a team level, as a first step towards reasoning to anticipate behavior within the team, and strategies for team-level interaction. We developed a formal model that allows us to investigate which conditions require coordination of agents to ensure task completion in a team setting and designed an agent-based framework for coordination of human-robot teaming to manage the roles, objectives, responsibilities and expectations for members of the team. We evaluated and further developed our dynamic task allocation model for sharing workload between human and robot team members by means of adaptive automation. We also explored various forms and uses of team-activity reporting.

Besides human-robot teaming we also addressed multi-robot task allocation. The model we developed establishes which tasks are assigned to robots and when a robot has to execute its assigned task. Task assignment takes into account both task failure and reliability due to the occurrence of unknown exogenous events. For testing this model we extended our augmented reality framework with a probabilistic model for generating virtual events and regulating their dynamics .

For the perception functionalities and autonomous action capabilities of the individual robots we developed several novel solutions and improvements: Adaptive traversability enables the UGV to negotiate difficult terrain by automatically changing the configuration of the flippers based on the terrain and the actual state of the robot (Figure 6); A new algorithm for data fusion and anomaly detection for localization and mapping combines input from various sensors for more reliable pose and orientation estimates; A significant change in the mapping architecture will allow for multi-sorties and multi-robots mapping, and will make it easier to maintain and update the map, thus supporting the long-term persistence objective; A multimodal detector that combines thermal, visual and 3D data detects victims more reliably in various conditions; An improved waypoint following for the UGV addresses the interaction between flipper control and path planning and execution; An improved waypoint following for the UAV makes flying possible in challenging environments, such as GPS-denied areas or near obstacles.

Finally, information about the disaster area needs to be collected, connected and made available within the team to ensure situation awareness of the various human team members. We started to develop a novel tactical display system addressing the requirements of the end-users. It is designed to support guided (a)synchronous information exchange between distributed or co-located actors through multi-modal interaction using a graphical user interface and spoken dialogue. Personalization and context-tailoring will be achieved through the utilization of an agent-based framework. To integrate speech-based interaction in the system we proposed a novel approach for building useful spoken language interfaces based on an object-oriented decomposition of the problem domain, and a behavior-oriented program composition, which is designed with re-use in mind, in order to enable system building and experimentation in an incremental fashion.

The most challenging technical objective for TRADR to go beyond the state of the art in disaster response robotics is the integration of a database system to collect and make available information across different sorties of a mission, and use it to improve the team abilities over time. We put an initial setup in place, which will be elaborated in the following years.

Another important goal in TRADR is to raise the awareness of robot- assisted disaster response among end users and to facilitate the adoption of these technologies. We have carried out a number of workshops with end users, where they could gain experience and at the same time provide us feedback. We have also organized a working group to formulate guidelines for the use of UAVs in disaster response missions.

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